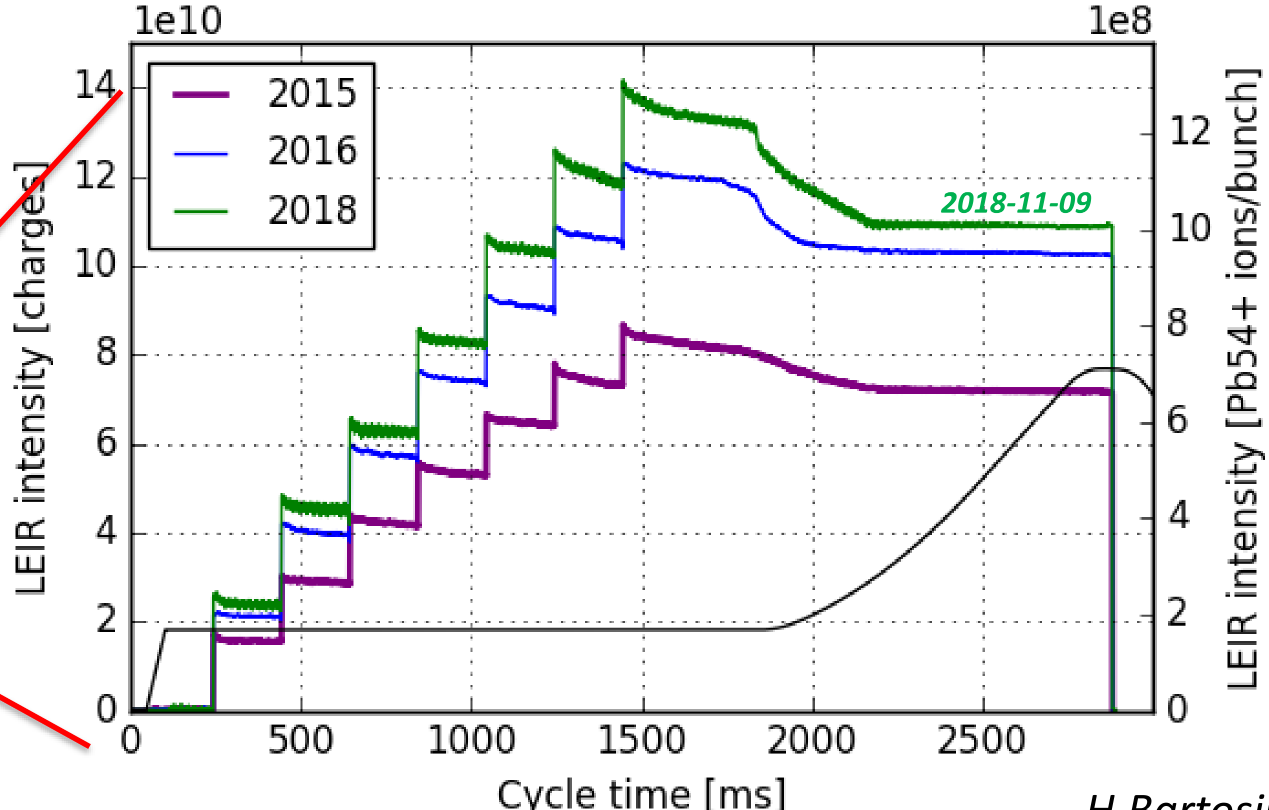
Overview of LEIR performance and operation during the LHC-Ion run

N.Biancacci for the LEIR/Linac3 team

MSWG meeting 2018 #18
14-12-2018

A new record year!



H.Bartosik

LEIR/Linac3 end of ion run celebration!

Two twin records on 2018-11-19 18:05 and 2018-11-09 01:47: ***10.88*** $\mathbf{10^{10}}$ *extracted!*

Outline

- Performance overview
  - NOMINAL 2+4
  - NOMINAL 3+6
  - Refined analysis (in progress)
- LEIR efficiency
  - Injection and transmission in accumulation
  - Capture and acceleration
- Lessons learnt and plans for the future

LEIR performance overview

Timeframe of data analysis :

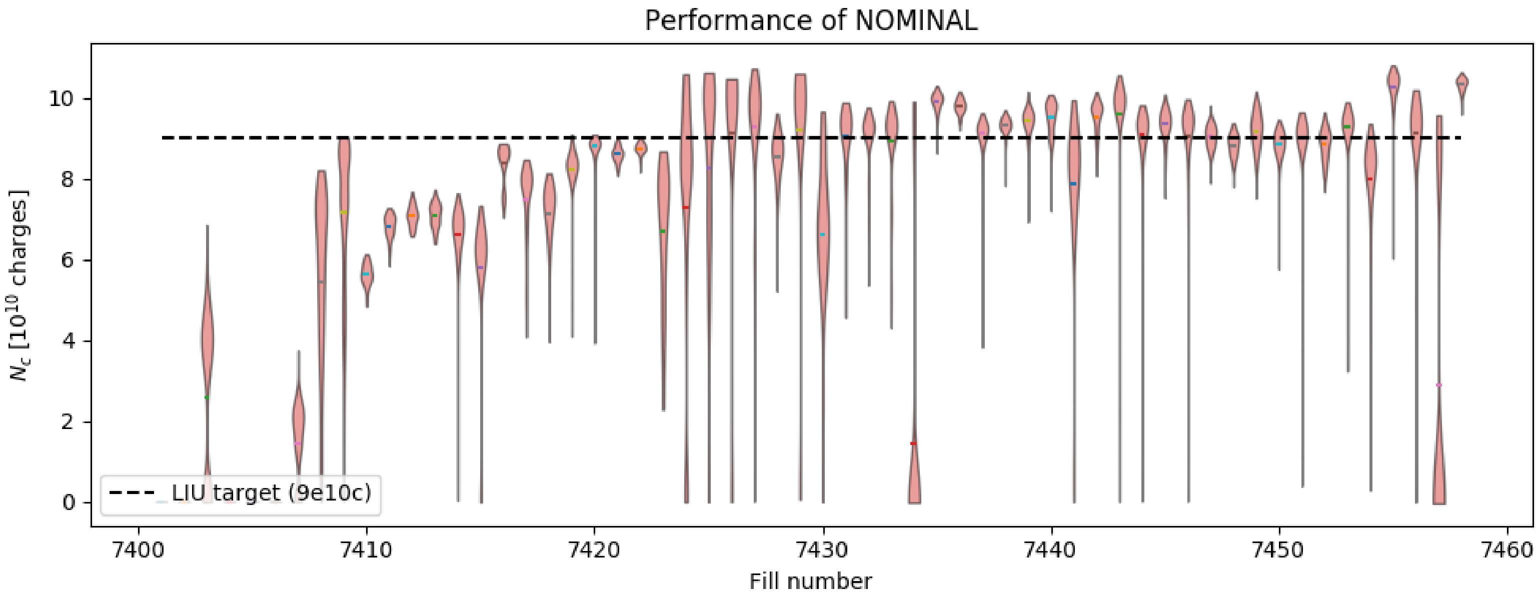
- LHC Ion run for LEIR started on 4/11/2018 and ended on 3/12/2018.
- ~93 LHC fills (7401 to 7493) analyzed.
- timespan from fill start to beginning of ramp / end of fill (if not ramped).
- 100ns (NOMINAL h2+4) and 75ns (NOMINAL h3+6) bunch spacing delivered when requested.
- NOMINAL h3+6 requested from fill 7459 onwards.

First order statistics analysis performed accounting for whatever intensty coming from Linac3 when filing.

Refinement done decoupling from Linac3 following 2 criteria:

- Average current per pulse: 30uA (filter on average delivered current)
- Minimum pulse intensity: 20uA (filter on sparks / bad shots)

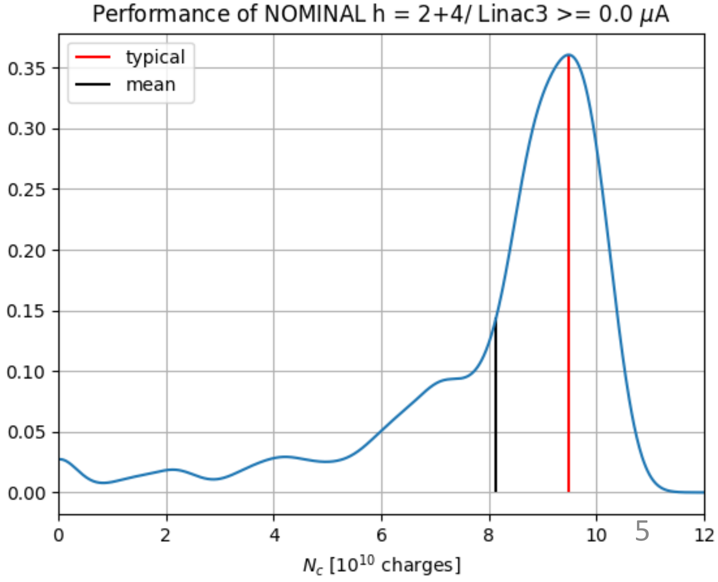
NOMINAL h = 2+4



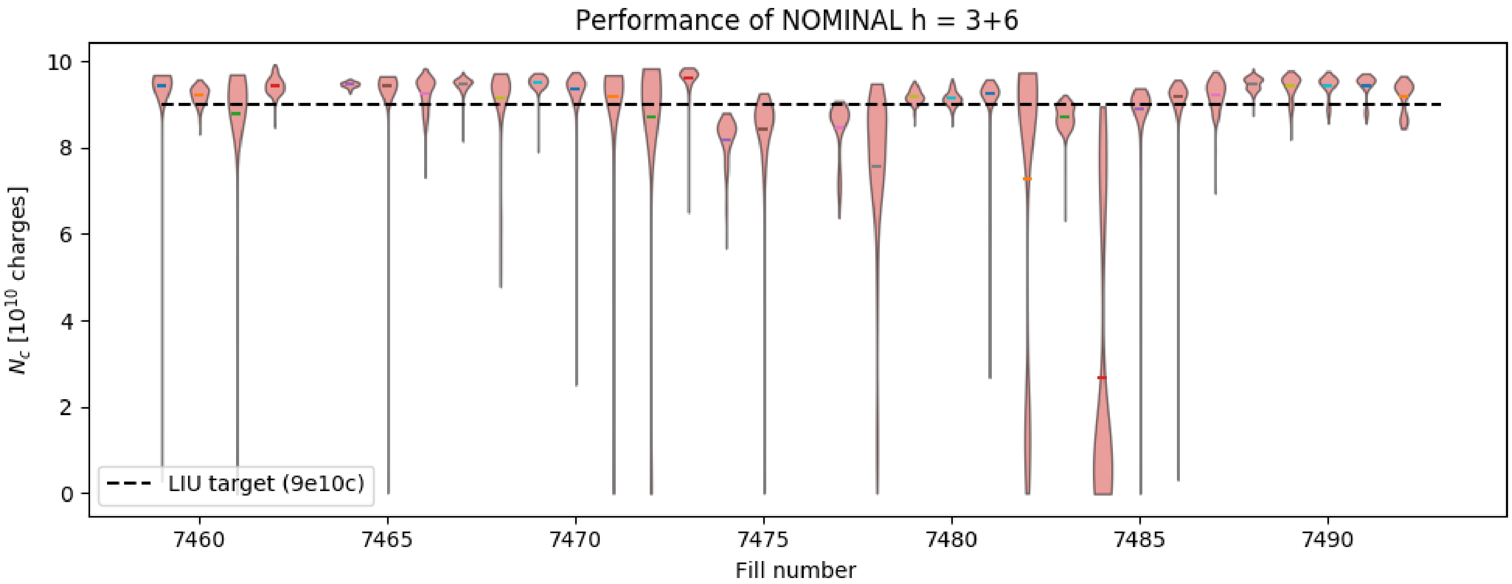
Statistical analysis on extracted intensity: all fill data considered, no filters on Linac3 current or machine occasional issues (Btrain, instabilities, etc.)

Mean: 8.14

Typical: 9.49 (machine in optimal state)



NOMINAL h = 3+6

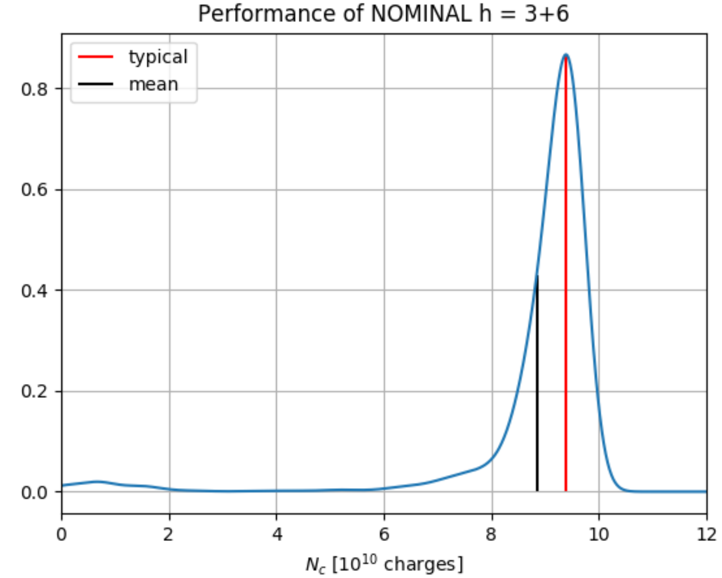


Statistical analysis on extracted intensity: all fill data considered, no filters on Linac3 current or machine occasional issues (Btrain, instabilities, etc.)

Mean: 8.84

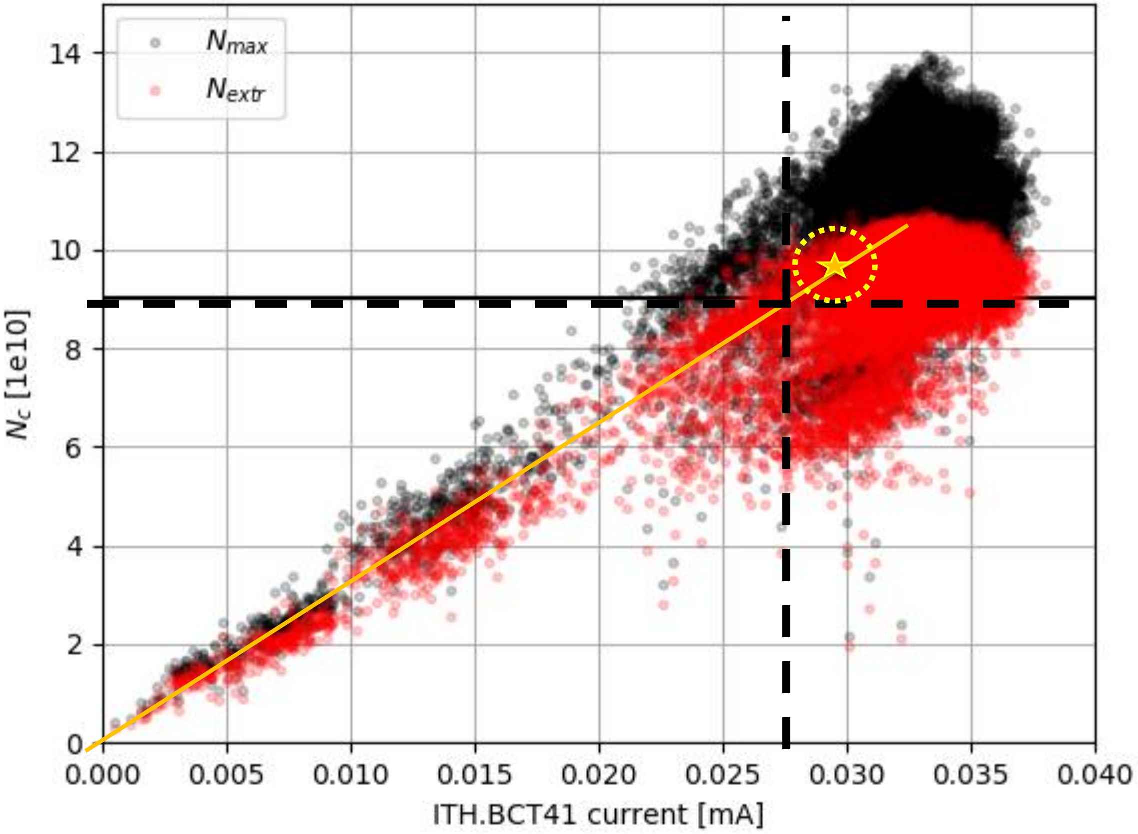
Typical: 9.39 (machine in optimal state)

Profited from the performance established during the first part of Ion run.

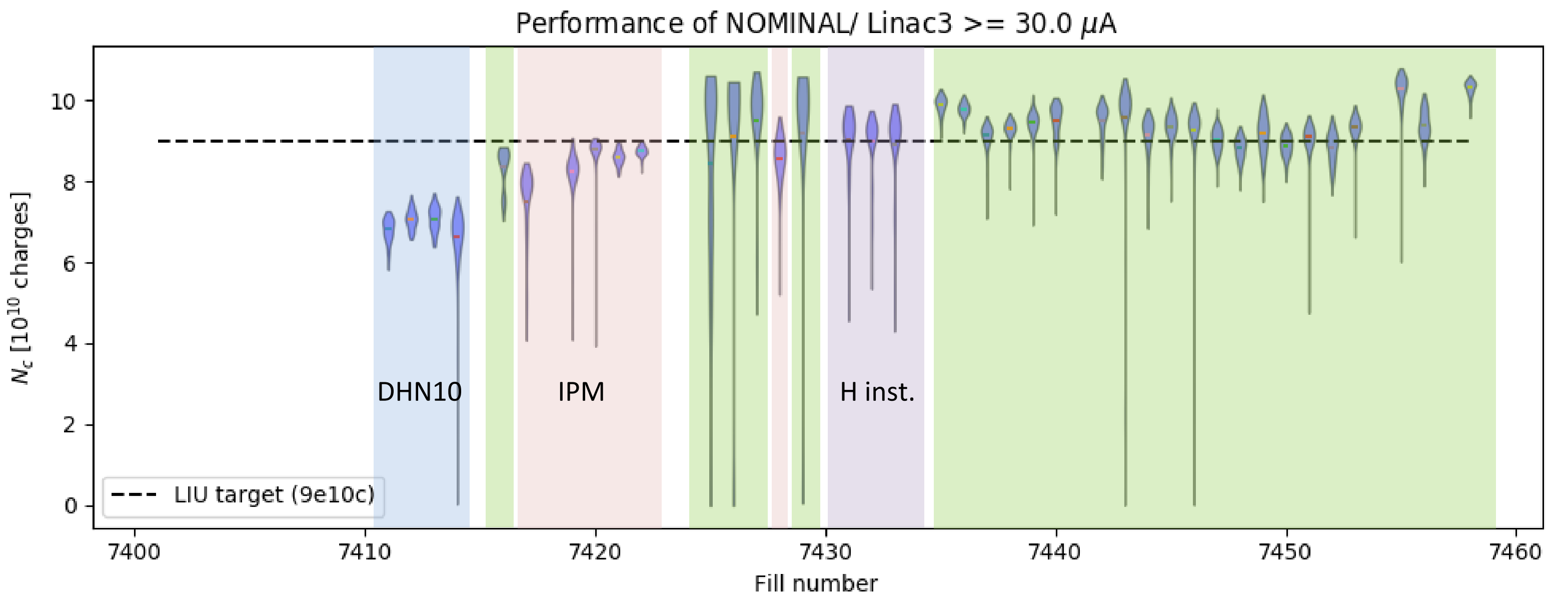


Dependence on Linac3 current

- Extracted intensity dependent on Linac3 current and machine injection efficiency.
- Most of LHC run at 30 uA → LEIR "comfortably" at LIU performance.



Refined analysis (in progress)



Main facts for NOMINAL 2+4:

Fills 7411 – 7414 -> Issues with trim on ETL.DHN10 (aircoil hysteresis).

Fills 7416 -> no issues but machine under optimization.

Fills 7417 – 7424 -> Issues with IPM induced kick (switch off).

Fills 7426 – 7427 -> Imported optimizations from MDNOM.

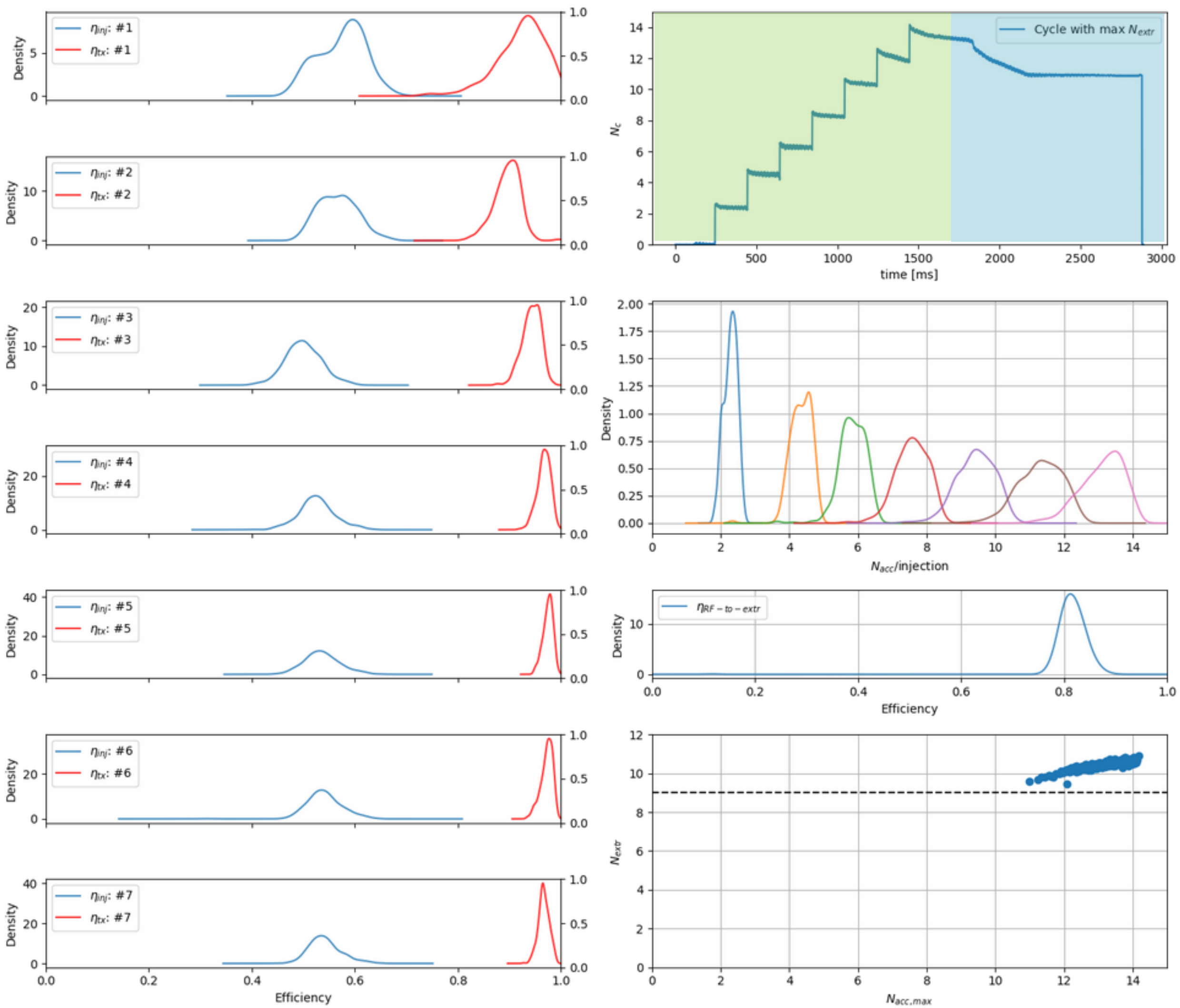
Fills 7428 -> Issue with IPM induced kick (switch off).

Fills 7431 – 7433 -> H instability (excessive cooling)

Fills 7429, 7434 – 7458 -> machine tuned for high intensity.

Before going to the issues… let's have a look at the **good performance**!

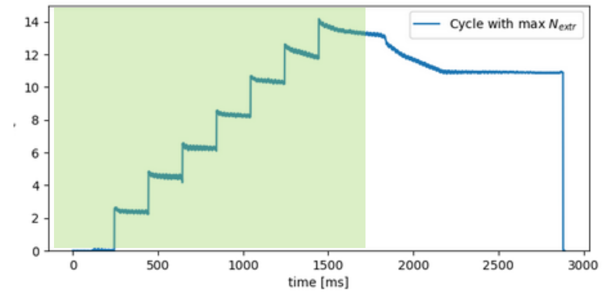
LEIR efficiency



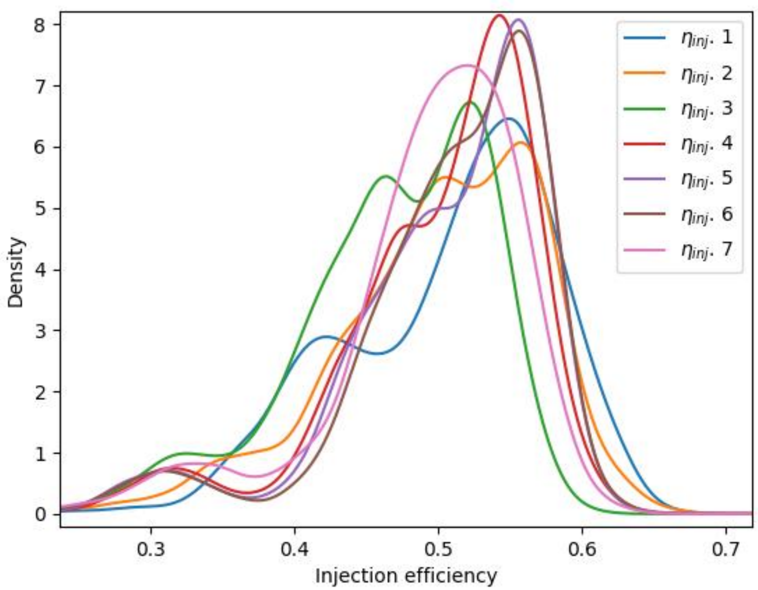
Two main segments:

1. **Injection and transmission efficiency** during accumulation.
2. **Capture and acceleration** (final dragging, cooler switch off + RF capture and acceleration).

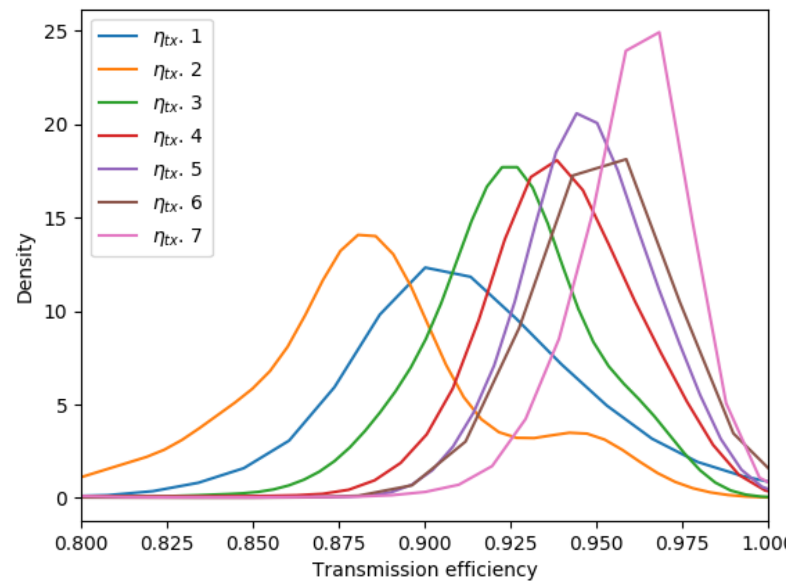
Injection and transmission



Injection



Transmission

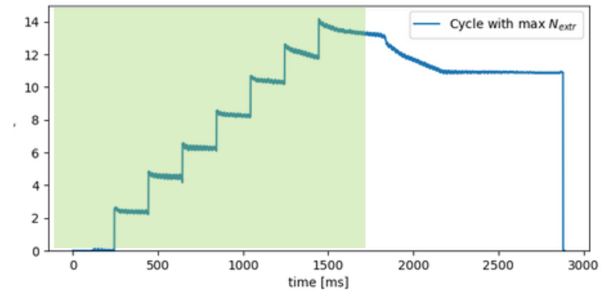


Good transmission efficiency:

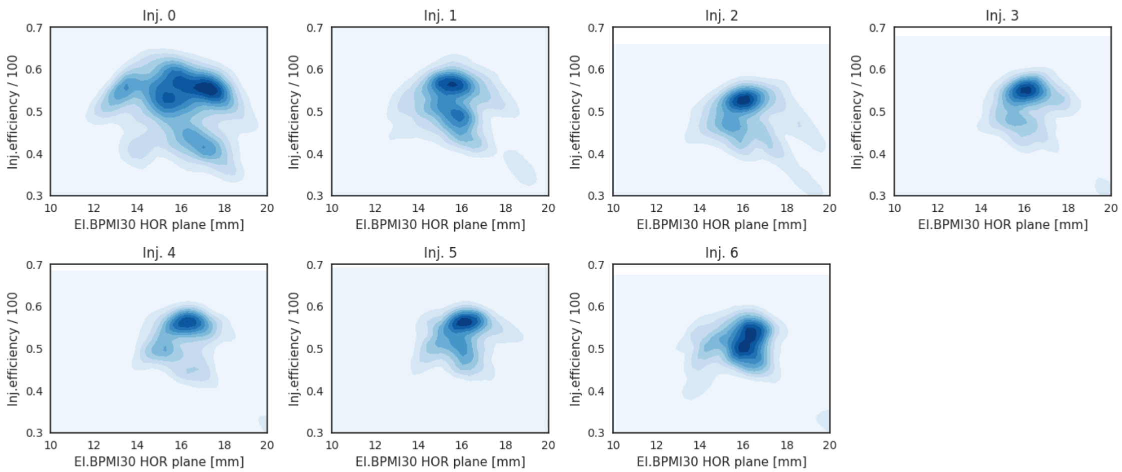
- from 85 – 100%
- Second injection a bit pathologic, still work to do ☺

Good injection efficiency but large spread between 0.4 and 0.6 -> stray fields!

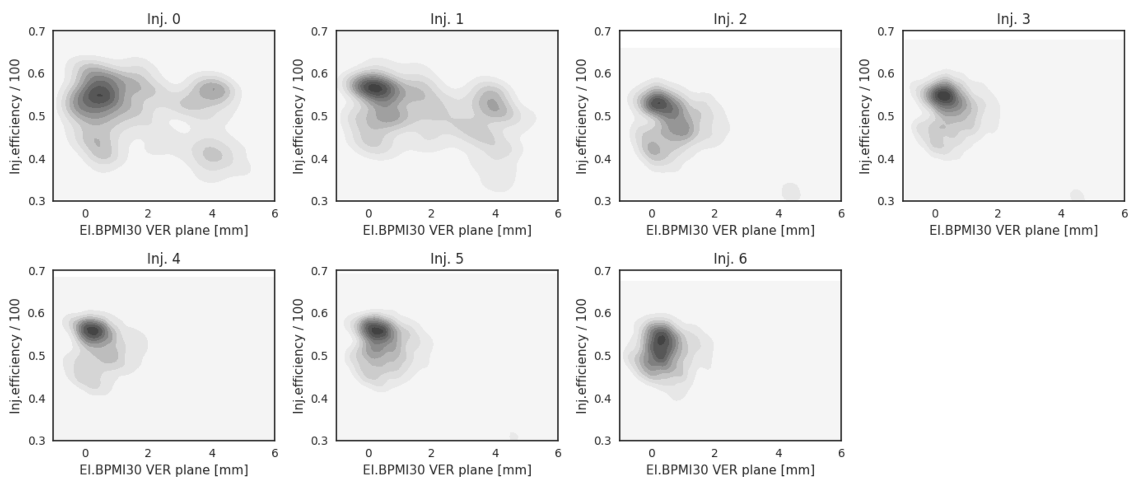
Injection and transmission



Stray fields effect on efficiency from BPMI30



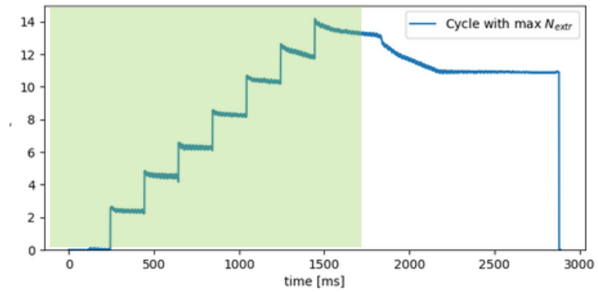
H plane



- Change of H,V positions due to super-cycle change.
- Mostly on first 2-3 injections
- Terrain for optimizers / equalizers!

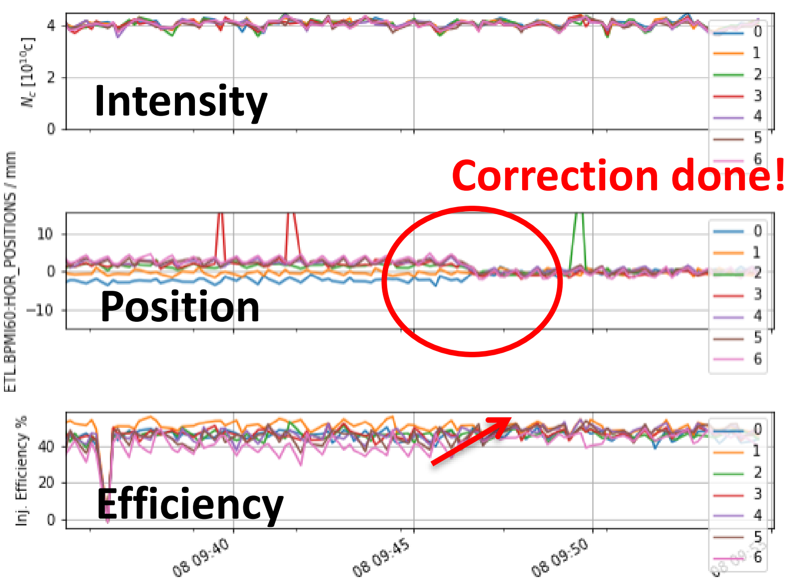
V plane

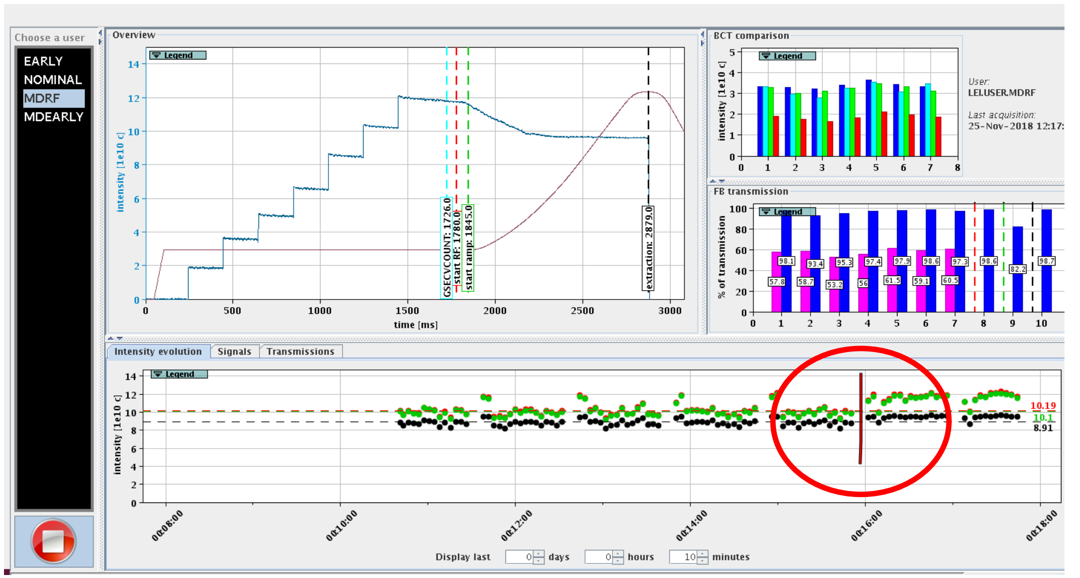
Injection and transmission



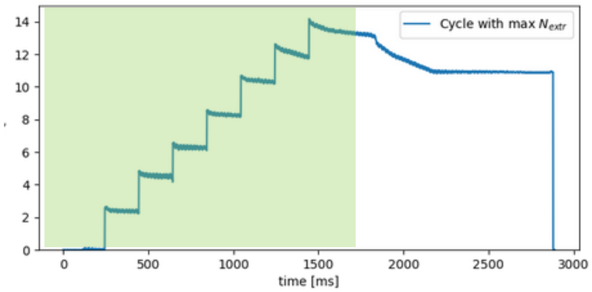
- Injection optimizers and equalizers: were a real performance steerers, largely profited from new BPMs (particularly BPMI60 at LF and BPMI30 at HF).

1. **Equalizer**: levels up the injection efficiencies applying a step by step correction on BHN10 kick function based on kick response measurement -> average correction over all the supercycle.



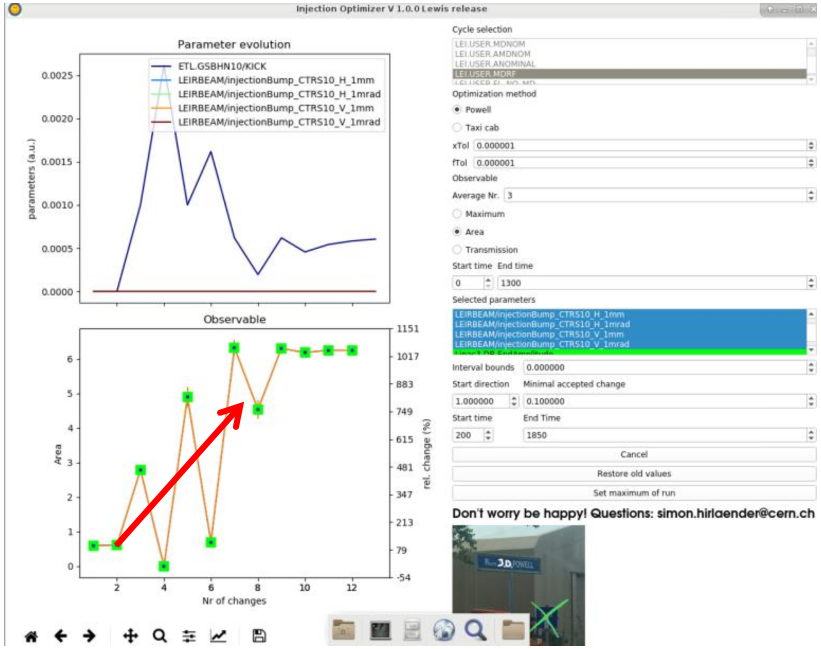


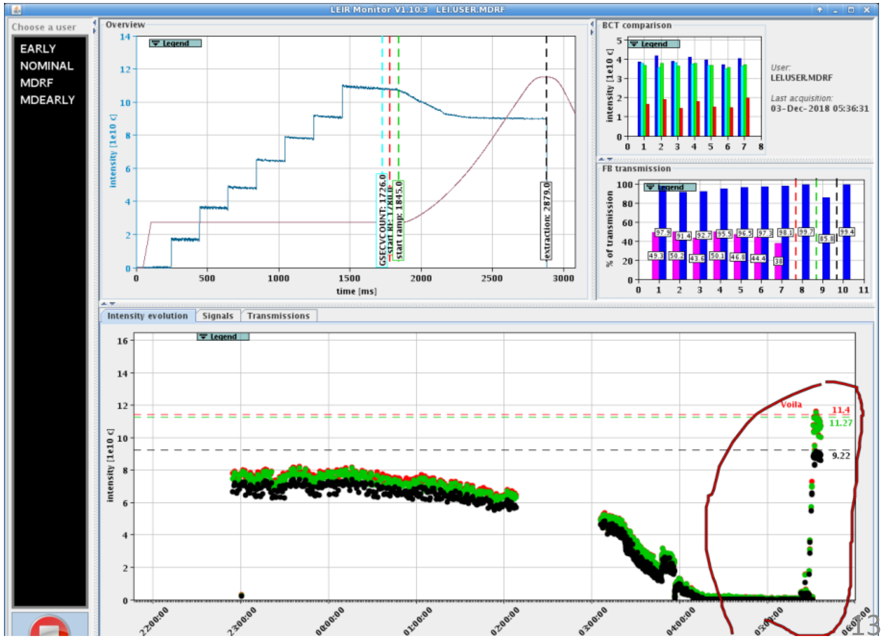
Injection and transmission



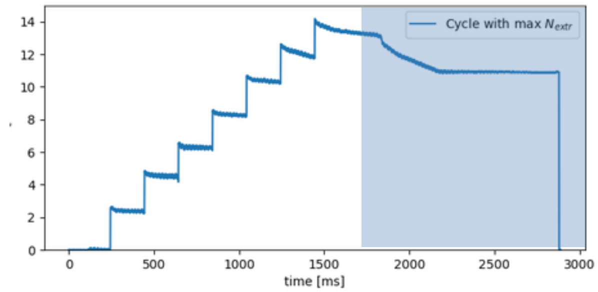
- Injection optimizers and equalizers: were a real performance steerers, largely profited from new BPMs (particularly BPMI60 at LF and BPMI30 at HF).

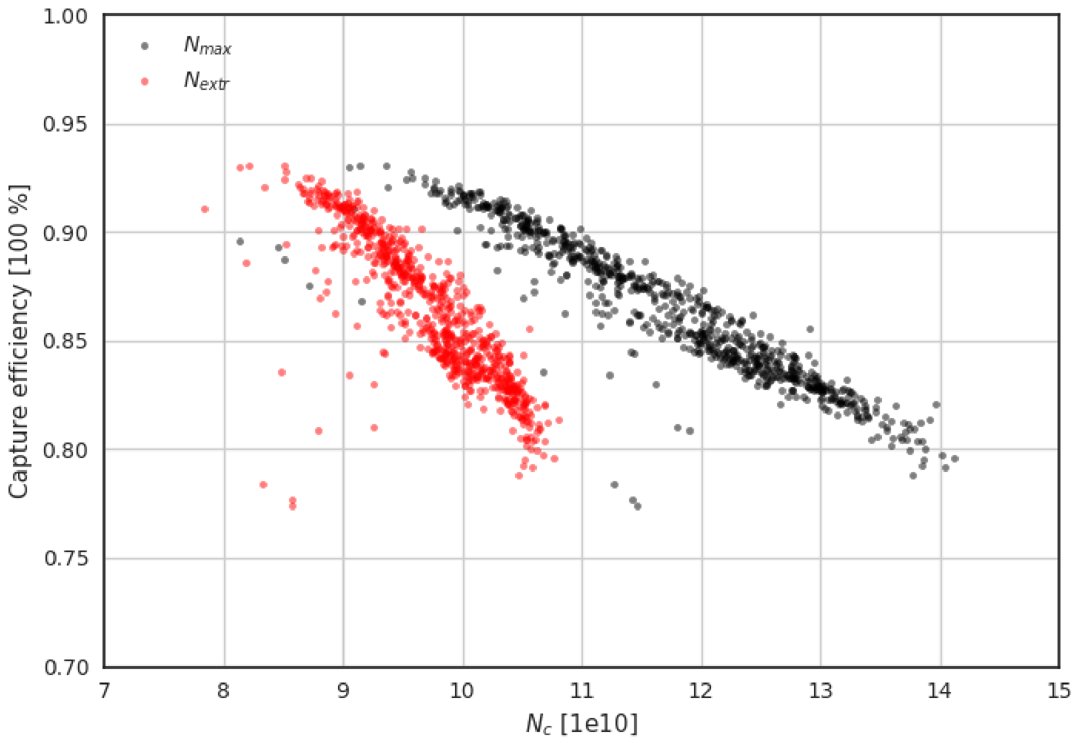
1. **Equalizer**: levels up the injection efficiencies applying a step by step correction on BHN10 kick function based on kick response measurement -> average correction over all the supercycle.
2. **Injection optimizer**: not only for injection (can basically steer everything). Based on Powell optimization algorithm -> steer V, H correctors in the line and observes intensity improvement.





Capture and acceleration

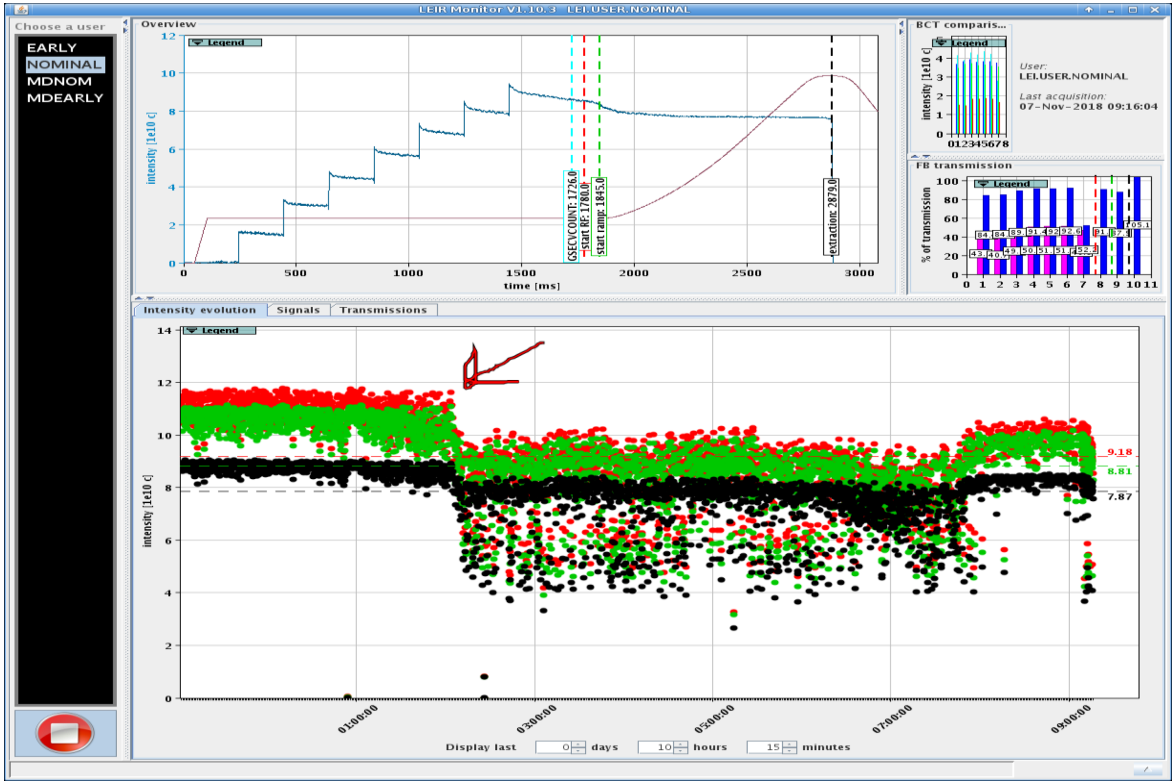




Data filtered for good Linac3 current:

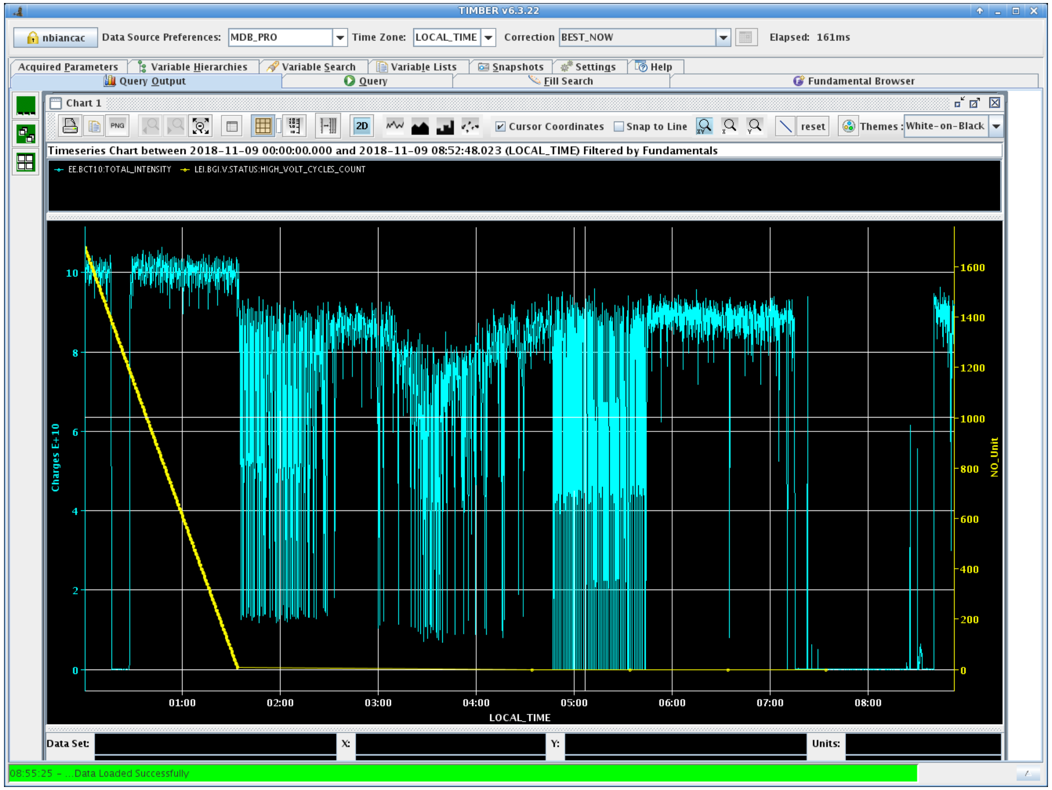
- Efficiency from 95% down to 80% depending on accumulated intensity.
- Decrease is more than linear -> close to LEIR roof?
- Higher/lower accumulation requires frev and electron gun voltage correction -> room for optimizers!

Lessons learnt: ETL.DHN10



- ETL.DHN10 is an aircoil corrector -> large hysteresis affects as well injection into LEIR.
- Already known issue, but little control/prevention so far.
- Fixed by tagging as “expert” the trim on LSA. Removed from YASP proposed correctors.
- Reappeared when ZERO cycle was inserted -> no settings for the corrector: unknown state.

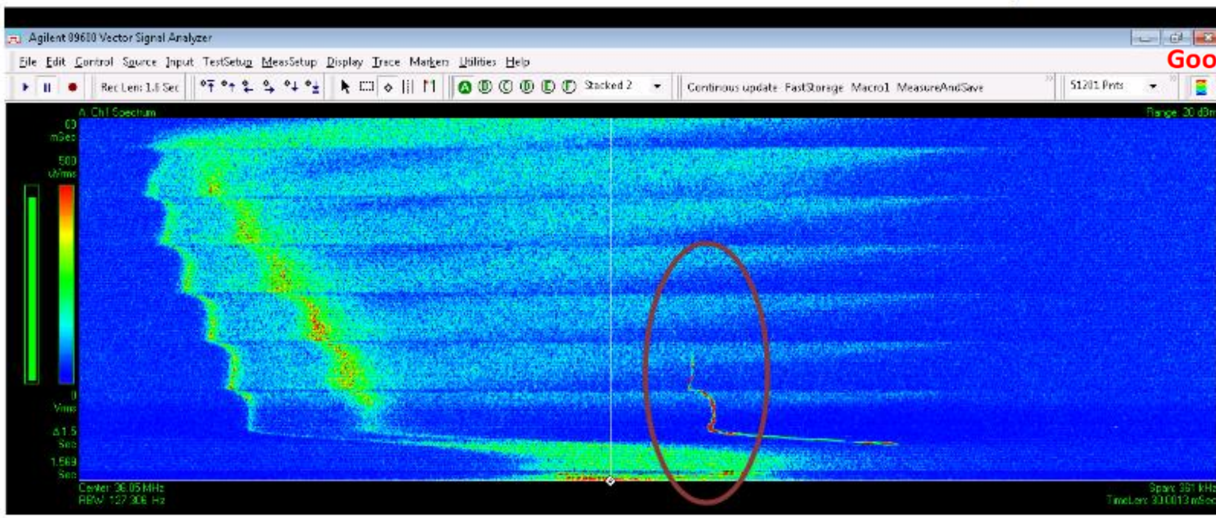
Lessons learnt: IPM kick

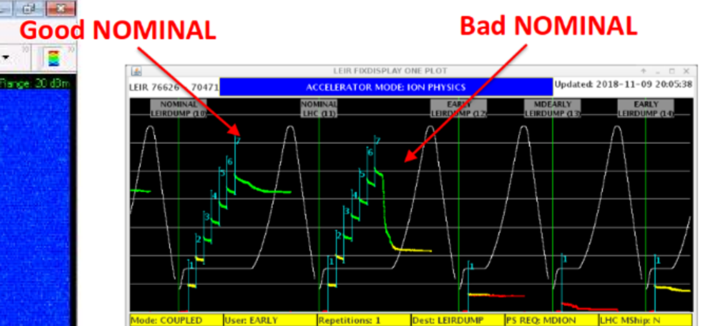


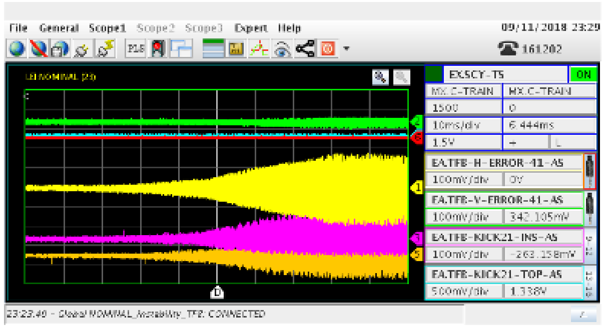
- IPM at full voltage applies a non negligible orbit kick -> change in cooling efficiency -> less accumulated intensity.
- Known issue, known solution (see [MSWG #15, 27-Oct-2017]())
- We could implement an automatic correction to DHV42 (H plane correction) and DHV12.V (vertical plane) once the device is ramped up.

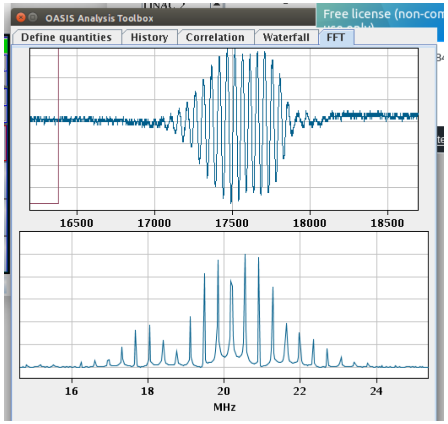
Lessons learnt: H instability

- H instabilities: related to excessive cooling in H plane and cured by careful angle adjustment.



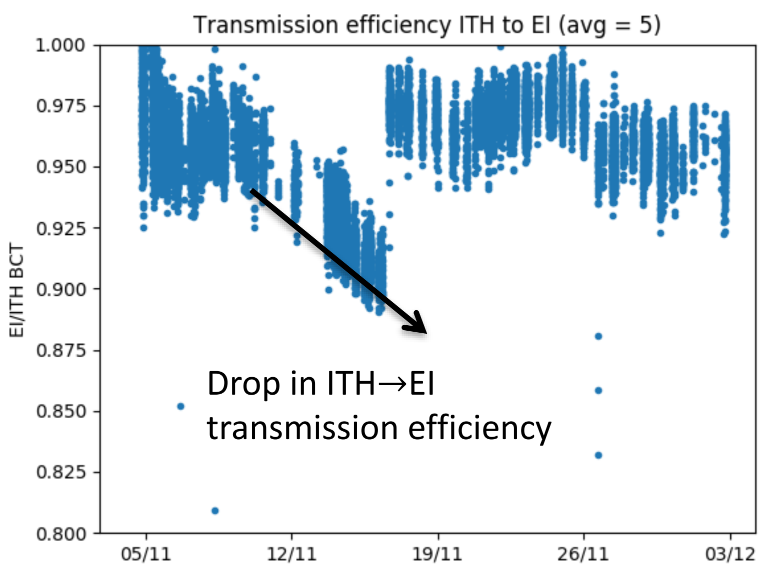


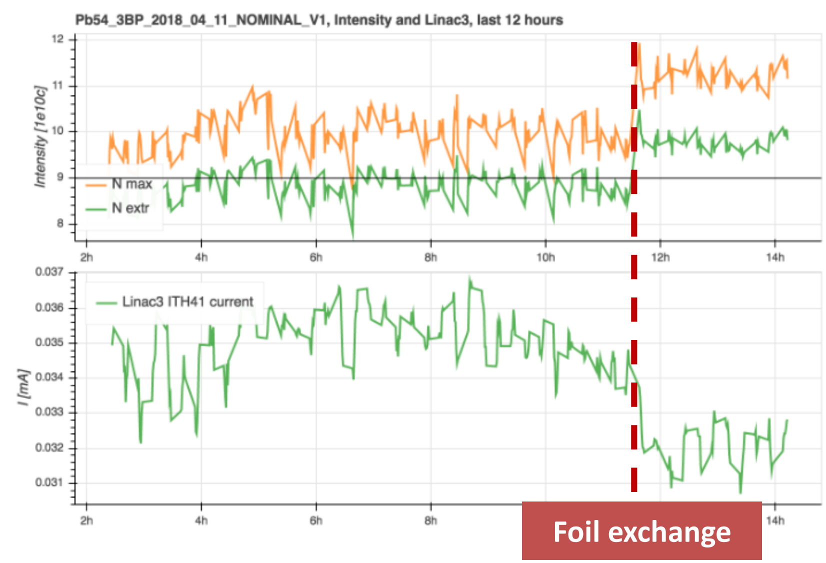




Lessons learnt: Stripper foil 1/2

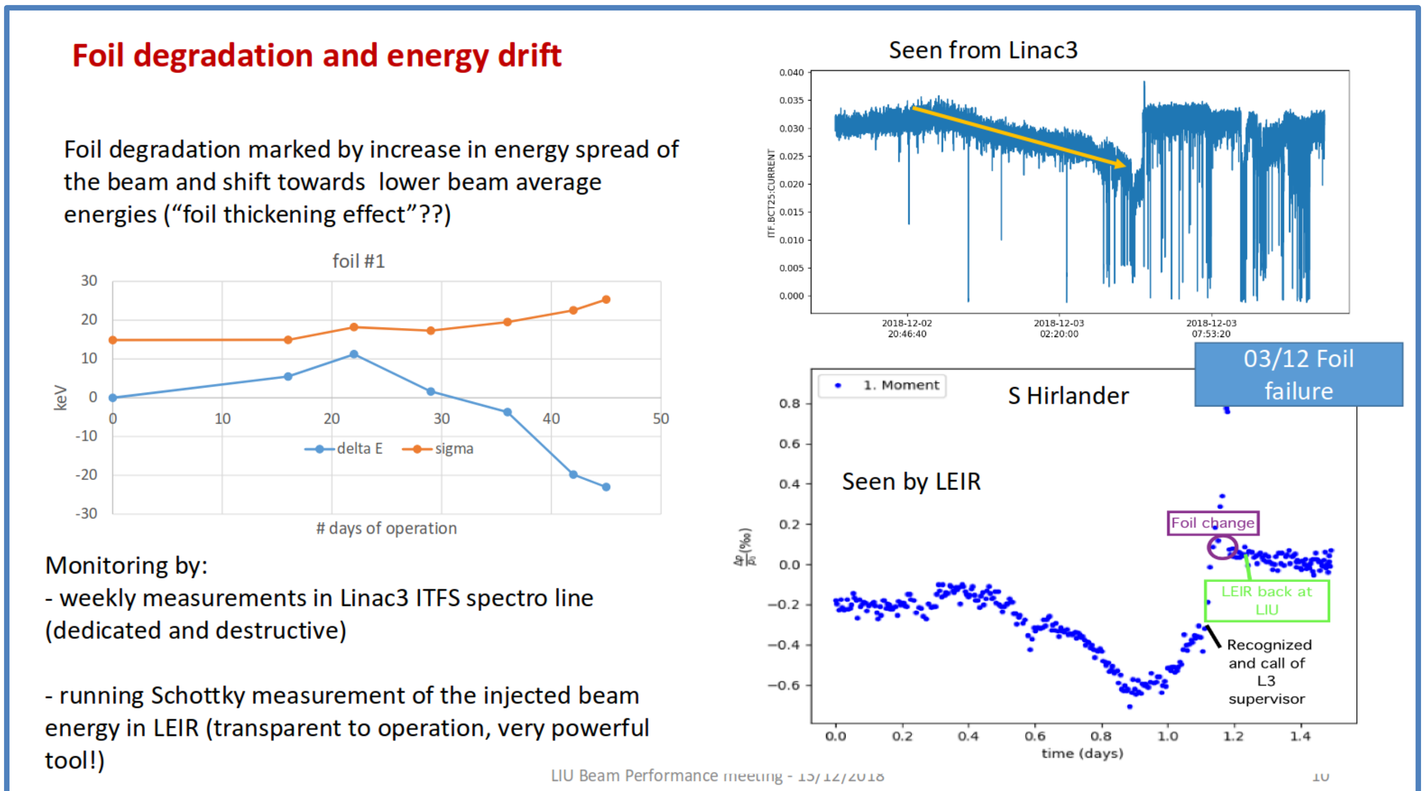
- Identified foil degradation signatures:
  1. lower ITH to EI transmission
  2. higher Linac3 current (other species) mean energy change → Input for foil exchange planning.





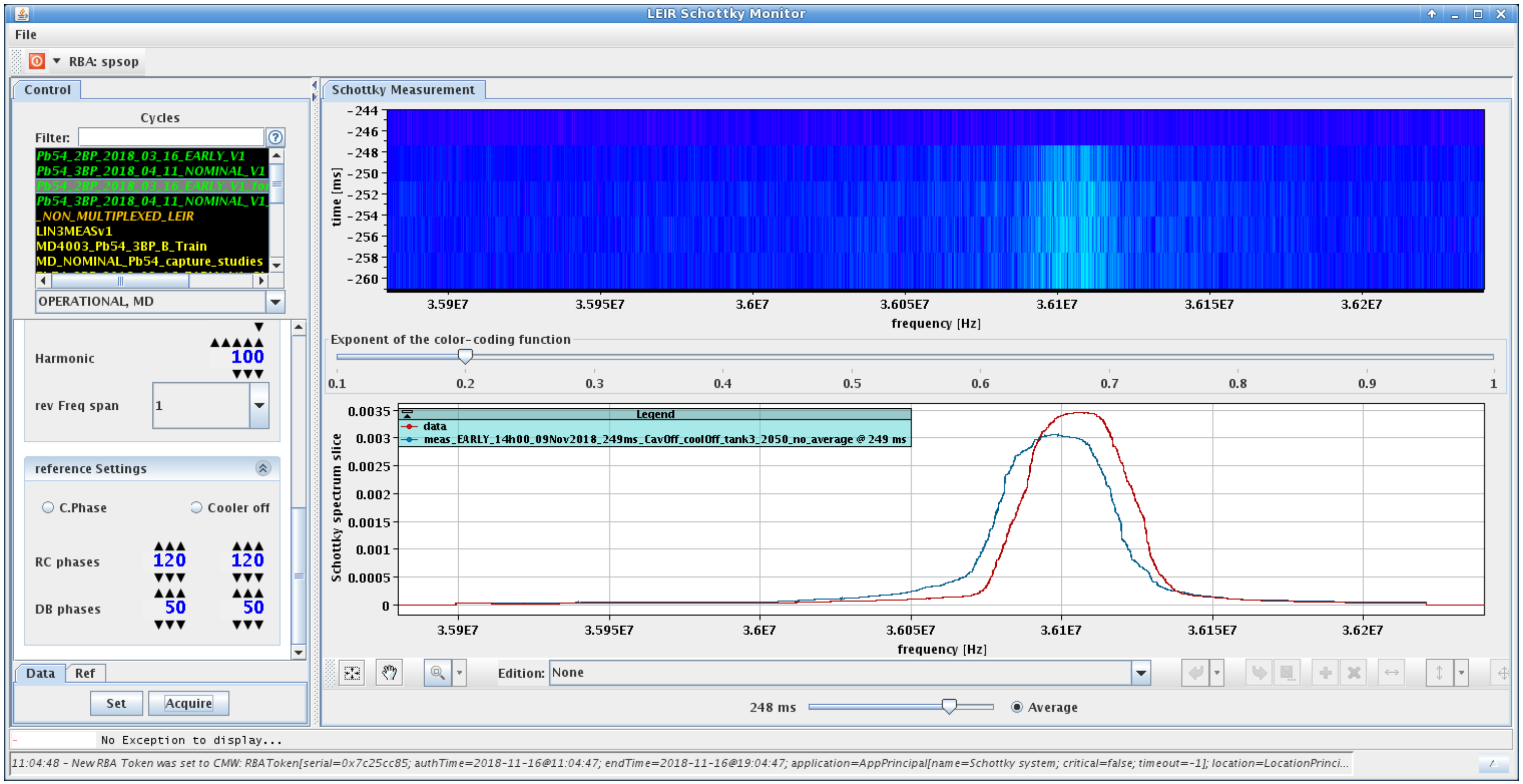
Lessons learnt: Stripper foil 2/2

- Identified foil degradation signatures:
  1. lower EI to ITH transmission
  2. higher Linac3 current (other species)
  3. mean energy change
- Recommendation for bi-weekly change of foils (interleaved with source refill)



G.Bellodi, S.Hirlander
LIU-BPM 13-12-2018

Lessons learnt: Mean energy shift



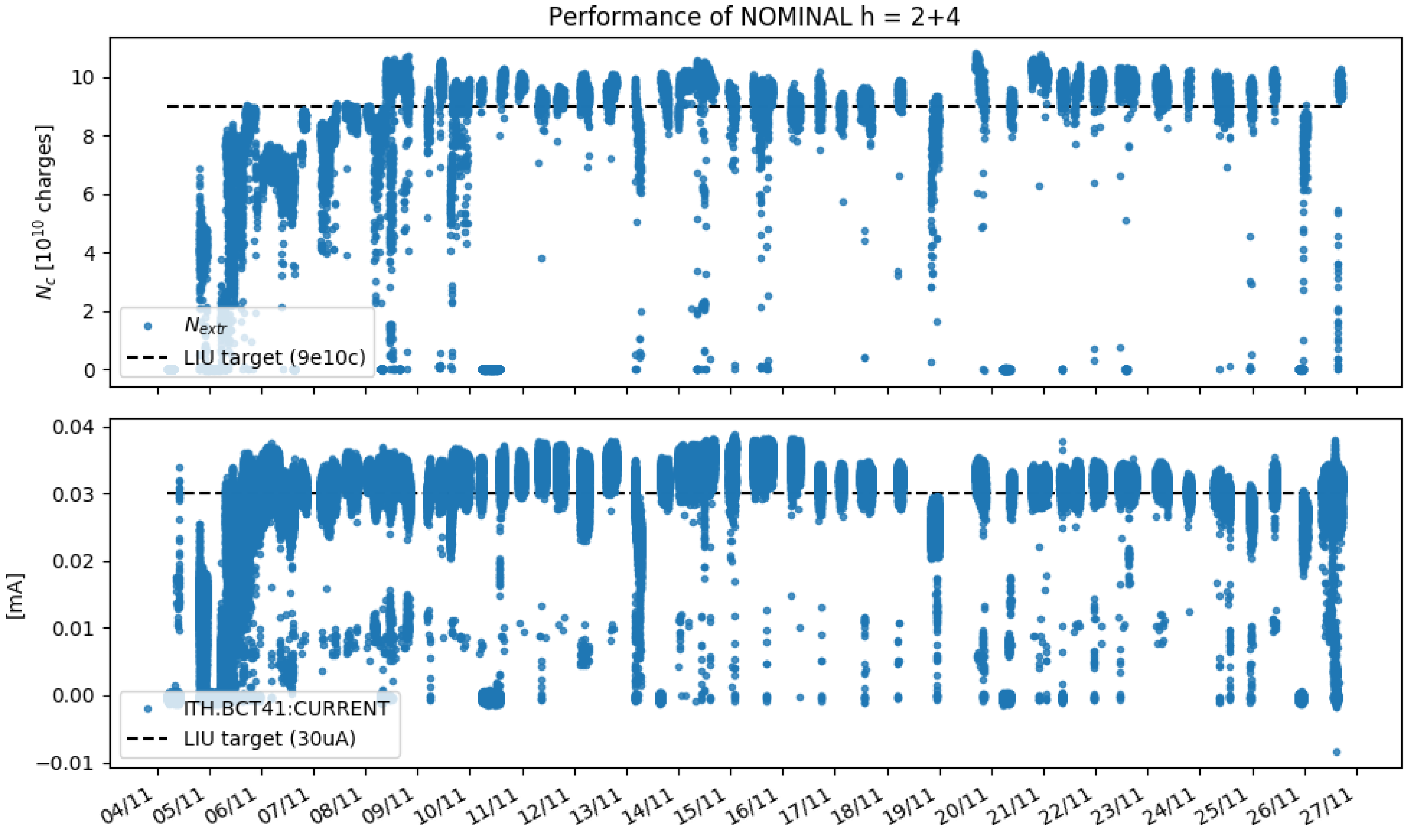
- Mean energy from Linac3 tracked thanks to the new Schottky application.
- Shift measured and corrected with Tank2-3 or ramping, debunching cavity.
- Logging allowed data tracking vs time -> useful to detect aging effects.

Summary and perspectives

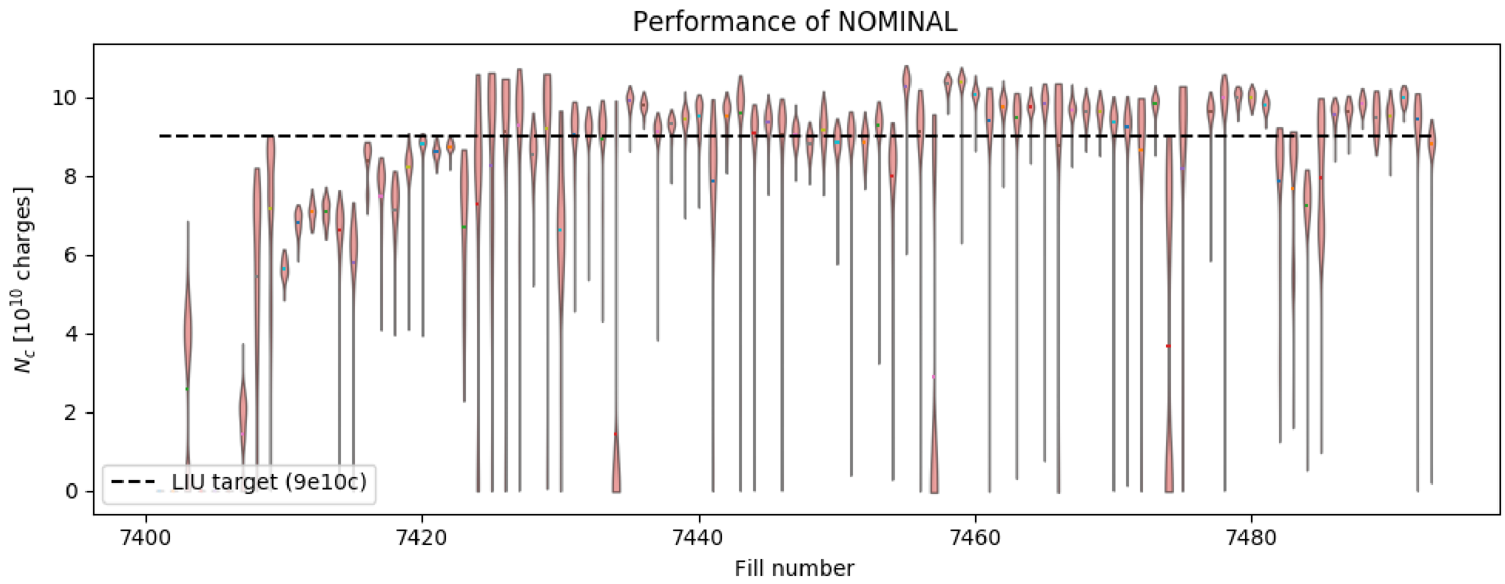
- Very rich, successful and "recordful" LEIR Ion run!
- We profited a lot from early machine startup in June: time to learn!
- Machine met LIU requirements on typical operation settings for both NOMINAL 2+4 and 3+6 type of beams. Main ingredients:
    1. Linac3 operating at 30 uA → LEIR "comfortably" at LIU performance thanks to the Linac3 team!
    2. Injection efficiencies around 50%
    3. Transmission efficiency above 80%
    4. Capture and acceleration efficiency above 85%.
    5. Strong and motivated team ☺
- Lessons learnt from the run:
    - Detrimental effect of DHN10: fixed.
    - IPM uncontrolled kick: automatic compensation scheme to be envisaged.
    - Foil degradation signatures: lower EI to ITH transmission + higher Linac3 current (other species) + mean energy change → Input for foil exchange planning every 2 weeks.
    - H instabilities: related to excessive cooling in H plane and cured by careful angle adjustment. Let's be prepared to identify the margins on stability knobs (cooler, chroma, damper).
    - Optimizers and equalizers were a real performance steerers: largely profited from new BPMs (particularly BPMI60 at LF and BPMI30 at HF): now machine learning!
    - Monitoring website (link): useful for tracking performance time evolution: OP app?
    - f_{rev} correction often required to accommodate lower accumulated intensity: feedback?
    - Acquired first turn-by-turn measurements: input for optics model refinement.
    - Others: new Schottky application, energy ramping rate from EI.BMPI30, …

Thanks for your attention!

Performance overview: NOMINAL h = 2+4



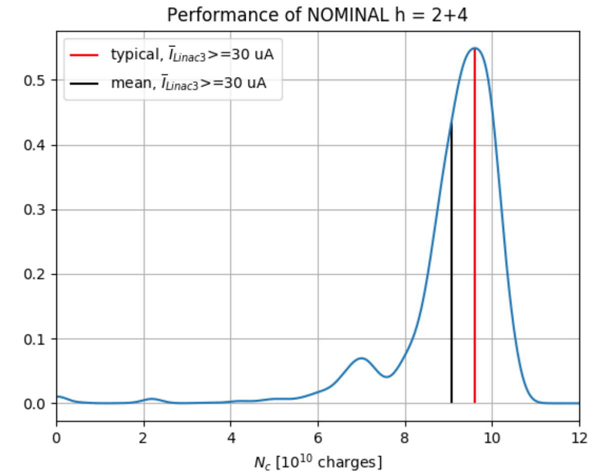
NOMINAL with Linac3 >= 30uA



Statistical analysis on extracted intensity: all fill data considered, filters on Linac3 current, not on machine occasional issues (Btrain, instabilities, etc.)

Mean: 9.06

Typical: 9.61 (machine in optimal state)



9.06890102339 9.60960960961

Performance overview: NOMINAL h = 3+6